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XIII. *Description of a Lamp-Micrometer, and the Method of using it.* By Mr. William Herschel, F. R. S.

Read January 31, 1782.

THE great difficulty of measuring very small angles, such as hardly amount to a few seconds, is well known to astronomers. Since I have been engaged in observations on double stars, I have had so much occasion for micrometers that would measure exceeding small distances exactly, that I have continually been endeavouring to improve these instruments.

The natural imperfections of the parallel wire micrometer in taking the distance of very close double stars are the following. When two stars are taken between the parallels, the diameters must be included. I have in vain attempted to find lines sufficiently thin to extend them across the centers of the stars so that their thickness might be neglected. The single threads of the silk-worm, with such lenses as I use, are so much magnified that their diameter is more than that of many of the stars. Besides, if they were much less than they are, the power of deflection of light would make the attempt to measure the distance of the centers this way fruitless: for I have always found the light of the stars to play upon those lines and separate their apparent diameters into two parts. Now since the spurious diameters of the stars thus included, to my certain knowledge, are continually changing according to the state of the air, and the length of time we look at them, we are, in

some respect, left at an uncertainty, and our measures taken at different times, and with different degrees of attention, will vary on that account. Nor can we come at the true distance of the centers of any two stars, one from another, unless we could tell what to allow for the semi-diameters of the stars themselves; for different stars have different apparent diameters, which, with a power of 227, may differ from each other (as I have experienced) as far as two seconds.

The next imperfection is that which arises from a deflection of light upon the wires when they approach very near to each other; for if this be owing to a power of repulsion lodged at the surface, it is easy to understand, that such powers must interfere with each other, and give the measures larger in proportion than they would have been if the repulsive power of one wire had not been opposed by a contrary power of the other wire.

Another very considerable imperfection of these micrometers is a continual uncertainty of the real zero. I have found, that the least alteration in the situation and quantity of light will affect the zero, and that a change in the position of the wires, when the light and other circumstances remain unaltered, will also produce a difference. To obviate this difficulty, whenever I took a measure that required the utmost accuracy, my zero was always taken immediately after, while the apparatus remained in the same situation it was in when the measure was taken; but this enhances the difficulty because it introduces an additional observation.

The next imperfection, which is none of the smallest, is that every micrometer that has hitherto been in use requires either a screw or a divided bar and pinion to measure the distance of the wires or divided image. Those who are acquainted

quainted with works of this kind are but too sensible how difficult it is to have screws that shall be perfectly equal in every thread or revolution of each thread; or pinions and bars that shall be so evenly divided as perfectly to be depended upon in every leaf and tooth to perhaps the two, three, or four thousandth part of an inch; and yet, on account of the small scale of those micrometers, these quantities are of the greatest consequence; an error of a single thousandth part inducing in most instruments a mistake of several seconds.

The last and greatest imperfection of all is, that these wire micrometers require a pretty strong light in the field of view: and when I had double stars to measure, one of which was very obscure, I was obliged to be content with less light than is necessary to make the wires perfectly distinct; and several stars on this account could not be measured at all, though otherwise not too close for the micrometer.

The instrument I am going to describe, which I call a Lamp-Micrometer, is free from all these defects, and has, moreover, to recommend it, the advantage of a very enlarged scale. The construction of it is as follows.

ABGCFE (fig. 1) is a stand nine feet high, upon which a semi-circular board *qbogp* is moveable upwards or downwards, in the manner of some fire-screens, as occasion may require, and is held in its situation by a peg *p* put into any one of the holes of the upright piece AB. This board is a segment of a circle of fourteen inches radius, and is about three inches broader than a semi-circle, to give room for the handles *rD*, *eP*, to work. The use of this board is to carry an arm *L*, thirty inches long, which is made to move upon a pivot at the center of the circle, by means of a string, which passes in a groove upon the edge of the semi-circle *pgohq*; the string is fastened

to a hook at *o* (not expressed in the figure being at the back of the arm *L*), and passing along the groove from *ob* to *q* is turned over a pulley at *q*, and goes down to a small barrel *e*, within the plane of the circular board, where a double-jointed handle *eP* commands its motion. By this contrivance we see the arm *L* may be lifted up to any altitude from the horizontal position to the perpendicular, or be suffered to descend by its own weight below the horizontal to the reverse perpendicular situation. The weight of the handle *P* is sufficient to keep the arm in any given position; but if the motion should be too easy, a friction spring applied to the barrel will moderate it at pleasure.

In front of the arm *L* a small slider, about three inches long, is moveable in a rabbet from the end *L* towards the center backwards and forwards. A string is fastened to the left side of the little slider, and goes towards *L*, where it passes round a pulley at *m*, and returns under the arm from *m*, *n*, towards the center, where it is led in a groove on the edge of the arm, which is of a circular form, upwards to a barrel (raised above the plane of the circular board) at *r*, to which the handle *rD* is fastened. A second string is fastened to the slider, at the right side, and goes towards the center, where it passes over a pulley *n*, and the weight *w*, which is suspended by the end of this string, returns the slider towards the center when a contrary turn of the handle permits it to act.

a and *b* are two small lamps, two inches high, $1\frac{1}{2}$ in breadth by $1\frac{1}{4}$ in depth. The sides, back, and top, are made so as to permit no light to be seen, and the front consists of a thin brass sliding door. The flame in the lamp *a* is placed three-tenths of an inch from the left side, three-tenths from the front, and half an inch from the bottom. In the lamp *b* it is placed at
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the same height and distance measuring from the right side. The wick of the flame consists only of a single very thin lamp-cotton thread; for the smallest flame being sufficient it is easier to keep it burning in so confined a place. In the top of each lamp must be a little slit, lengthways, and also a small opening in one side near the upper part, to permit air enough to circulate to feed the flame. To prevent every reflection of light, the side opening of the lamp *a* should be to the right, and that of the lamp *b* to the left. In the sliding door of each lamp is made a small hole with the point of a very fine needle just opposite the place where the wicks are burning, so that when the sliders are shut down, and every thing dark, nothing shall be seen but two fine lucid points of the size of two stars of the third or fourth magnitude. The lamp *a* is placed so that its lucid point may be in the center of the circular board where it remains fixed. The lamp *b* is hung to the little slider which moves in the rabbet of the arm, so that its lucid point, in a horizontal position of the arm, may be on a level with the lucid point in the center. The moveable lamp is suspended upon a piece of brass fastened to the slider by a pin exactly behind the flame upon which it moves as a pivot. The lamp is balanced at the bottom by a leaden weight, so as always to remain upright, when the arm is either lifted above, or depressed below, the horizontal position. The double-jointed handles *rD*, *eP*, consist of light deal rods, ten feet long, and the lowest of them may have divisions, marked upon it near the end *P*, expressing exactly the distance from the central lucid point in feet, inches, and tenths.

From this construction we see, that a person at a distance of ten feet may govern the two lucid points, so as to bring them into any required position south or north preceding or following,

from 0 to 90° by using the handle *P*, and also to any distance from six-tenths of an inch to five or six and twenty inches by means of the handle *D*. If any reflection or appearance of light should be left from the top or sides of the lamps, a temporary screen, consisting of a long piece of paste-board, or a wire frame covered with black cloth, of the length of the whole arm and of any required breadth, with a slit of half an inch broad in the middle, may be affixed to the arm by four bent wires projecting an inch or two before the lamps, situated so that the moveable lucid point may pass along the opening left for that purpose.

Fig. 2. represents part of the arm *L*, half the real size; *S* the slider; *m* the pulley, over which the cord *xyzt* is returned towards the center; *v* the other cord going to the pulley *n* of fig. 1. *R* the brass piece moveable upon the pin *c*, to keep the lamp upright. At *R* is a wire rivetted to the brass piece, upon which is held the lamp by a nut and screw. Fig. 3. 4. represent the lamps *a*, *b*, with the sliding doors open, to shew the situation of the wicks. *W* is the leaden weight with a hole *d* in it, through which the wire *R* of fig. 2. is to be passed when the lamp is to be fastened to the slider *S*. Fig. 5. represents the lamp *a* with the sliding door shut; *l* the lucid point; and *ik* the openings at the top, and *s* at the sides for the admission of air.

Every ingenious artist will soon perceive that the motions of this micrometer are capable of great improvement by the application of wheels and pinions, and other well known mechanical resources; but, as the principal object is only to be able to adjust the two lucid points to the required position and distance, and to keep them there for a few minutes, while the observer

observer goes to measure their distance, it will not be necessary to say more upon the subject.

I am now to shew the application of this instrument. It is well known to opticians and others, who have been in the habit of using optical instruments, that we can with one eye look into a microscope or telescope, and see an object much magnified, while the naked eye may see a scale upon which the magnified picture is thrown. In this manner I have generally determined the power of my telescopes; and any one who has acquired a facility of taking such observations will very seldom mistake so much as one in fifty in determining the power of an instrument, and that degree of exactness is fully sufficient for the purpose.

The Newtonian form is admirably adapted to the use of this micrometer; for the observer stands always erect, and looks in a horizontal direction, notwithstanding the telescope should be elevated to the zenith. Besides, his face being turned away from the object to which his telescope is directed, this micrometer may be placed very conveniently without causing the least obstruction to the view: therefore, when I use this instrument I put it at ten feet distance from the left eye, in a line perpendicular to the tube of the telescope, and raise the moveable board to such a height that the lucid point of the central lamp may be upon a level with the eye. The handles, lifted up, are passed through two loops fastened to the tube, just by the observer, so as to be ready for his use. I should observe, that the end of the tube is cut away so as to leave the left eye intirely free to see the whole micrometer.

Having now directed the telescope to a double star, I view it with the right eye, and at the same time with the left see it pro-

jected upon the micrometer: then, by the handle P, which commands the position of the arm, I raise or depress it so as to bring the two lucid points to a similar situation with the two stars; and, by the handle D, I approach or remove the moveable lucid point to the same distance of the two stars, so that the two lucid points may be exactly covered by, or coincide with the stars. A little practice in this business soon makes it easy, especially to one who has already been used to look with both eyes open.

What remains to be done is very simple. With a proper rule, divided into inches and fortieth parts, I take the distance of the lucid points, which may be done to the greatest nicety, because, as I observed before, the little holes are made with the point of a very fine needle. The measure thus obtained is the tangent of the magnified angle under which the stars are seen to a radius of ten feet; therefore, the angle being found and divided by the power of the telescope gives the real angular distance of the centers of a double star.

For instance, September 25, 1781, I measured α Herculis with this instrument. Having caused the two lucid points to coincide exactly with the stars center upon center, I found the radius or distance of the central lamp from the eye 10 feet 4,15 inches; the tangent or distance of the two lucid points 50,6 fortieth parts of an inch; this gives the magnified angle $35'$, and dividing by the power 460, which I used, we obtain $4''\ 34''$ for the distance of the centers of the two stars. The scale of the micrometer at this very convenient distance, with the power of 460 (which my telescope bears so well upon the fixed stars that for near a twelve-month past I have hardly used any other) is above a quarter of an inch to a second; and by putting on my power of 932, which in very fine evenings is

extremely distinct, I obtain a scale of more than half an inch to a second, without increasing the distance of the micrometer; whereas the most perfect of my former micrometers, with the same instrument, had a scale of less than the two thousandth part of an inch to a second.

The measures of this micrometer are not confined to double stars only, but may be applied to any other objects that require the utmost accuracy, such as the diameters of the planets or their satellites, the mountains of the moon, the diameters of the fixed stars, &c.

For instance, October 22, 1781, I measured the apparent diameter of α Lyræ; and judging it of the greatest importance to increase my scale as much as convenient, I placed the micrometer at the greatest convenient distance, and (with some trouble, for want of longer handles, which might easily be added) took the diameter of this star by removing the two lucid points to such a distance as just to inclose the apparent diameter. When I measured my radius it was found to be twenty-two feet six inches. The distance of the two lucid points was *about* three inches; for I will not pretend to *extreme* nicety in this observation, on account of the very great power I used, which was 6450. From these measures we have the magnified angle $38' 10''$: this divided by the power gives $0''.355$ for the apparent diameter of α Lyræ. The scale of the micrometer, on this occasion, was no less than 8,443 inches to a second, as will be found by multiplying the natural tangent of a second with the power and radius in inches.

November 28, 1781, I measured the diameter of the new star; but the air was not very favourable, for this singular star was not so distinct with 227 that evening as it generally is

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with 460: therefore, without laying much stress upon the exactness of the observation, I shall only report it to exemplify the use of the micrometer. My radius was 35 feet 11 inches. The diameter of the star, by the distance of the lucid points, was 2,4 inches, and the power I used 227: hence the magnified angle is found $19'$, and the real diameter of the star $5'',022$. The scale of this measure, 474 millesimals of an inch, or almost half an inch to a second.



